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Measurements of low mass e^+e^- pairs in p+p and Au+Au collisions with the HBD upgrade of the PHENIX detector

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Abstract

The Hadron Blind Detector (HBD) was developed, installed and successfully operated in the PHENIX detector during RHIC Runs in 2009 (p+p) and 2010 (Au+Au). The HBD is a windowless Cherenkov detector, operated with CF_4 gas in proximity focus configuration. It uses triple GEM elements for signal amplification with CsI photocathode evaporated on top of the first GEM. The purpose of the HBD is to reduce the combinatorial background from the dielectron invariant mass spectrum by recognizing and rejecting e^+ or e^- originating from π^0 Dalitz decays and conversion. This article reports on the in-beam performance of the HBD.

Keywords: Hot and Dense Nuclear Matter, Low Mass Dileptons, Hadron Blind Detector, GEM

1. Low Mass Dileptons

Dileptons are important probes in the investigation of the hot and dense matter formed in heavy ion collisions. Their importance lays in the fact that they interact only electromagnetically so their path from the interaction region to the detectors is almost undisturbed. Dileptons can provide information about the matter properties in the early stages of the collisions where deconfinement and chiral symmetry restoration are expected to take place.

Results by the PHENIX collaboration from RHIC Run in 2004 [1], where Au+Au collisions were measured at $\sqrt{s_{NN}}$ = 200 GeV, show that the dielectron yield in the mass region m_{ee} = 0.15 - 0.75 GeV/c^2 is larger by a factor 4.7 +/- 0.4(stat.) +/- 1.5(syst.) +/- 0.9(model) compared to the expected hadronic contributions (Figure 1, left). At the same time such enhancement is not seen in p+p collisions [2]. The measurement of dileptons in heavy ion collisions is a particularly challenging task due to the large combinatorial background, especially in the low mass region (m < 1 GeV/c^2). The results from the 2004 Run [1] suffered from a relatively low signal-to-background ratio S/B~1/200 in the low mass region (Figure 1, right) and a considerable reduction of the combinatorial background is needed in order to improve the significance of the results and further characterize the excess yield.

The main sources of the combinatorial background are π^0 Dalitz decays ($\pi^0 \rightarrow \gamma e^+e^-$) and photon conversions ($\pi^0 \rightarrow \gamma\gamma \rightarrow \gamma e^+e^-$) in which only one of the leptons is reconstructed by the central arm detectors. However the e^+e^- pairs from these two sources have a very small opening angle and this feature can be exploited to recognize them and reject them. This is the goal of the Hadron Blind Detector (HBD), which is located inside the magnetic field-free region in PHENIX, where the opening angle of the e^+e^- pairs is preserved. The electron tracks detected by the central arms which have a corresponding double hit in the HBD are considered to originate from π^0 Dalitz decays or conversions and are therefore rejected.

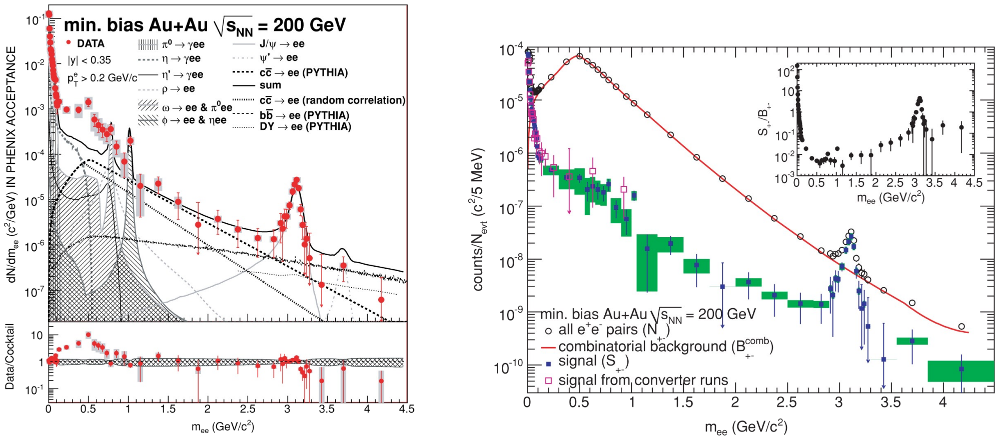

Figure 1: Left: the inclusive mass spectrum of e^+e^- pairs in the PHENIX acceptance in Au+Au collisions. The points represent the data and the lines show the expected hadronic contribution. Right: the signal compared to the combinatorial background [1].

2. The Hadron Blind Detector

2.1. Concept

The HBD (Figure 2, left) is a windowless Cherenkov detector, using CF_4 as both radiator (L_{rad}=50 cm) and active gas. It has triple GEM [3] elements for signal amplification with a CsI photocathode evaporated on top of the first GEM (Figure 2, right). It works in a proximity focus configuration without a mirror or a window and the Cherenkov light forms a circular blob image directly on the photocathode. The choice of CF_4 for the radiator and the active gas in the windowless configuration results in a very large bandwidth from ~6 eV given by the CsI threshold to ~11.5 eV determined by CF_4 cut-off. Consequently the HBD has a very large figure of merit[1] N_0 ~800 cm^{-1} (under ideal conditions) resulting in a high electron detection efficiency crucial for achieving a good double-hit resolution.

In order to reject the overwhelming hadronic background, the HBD is operated in the so-called reverse bias mode, where a reverse electric field between the mesh and the first GEM is applied, as depicted in Figure 2 (right). Hence most of the ionization charge from dE/dx is repelled from the GEMs and the detector is effectively made hadron blind.

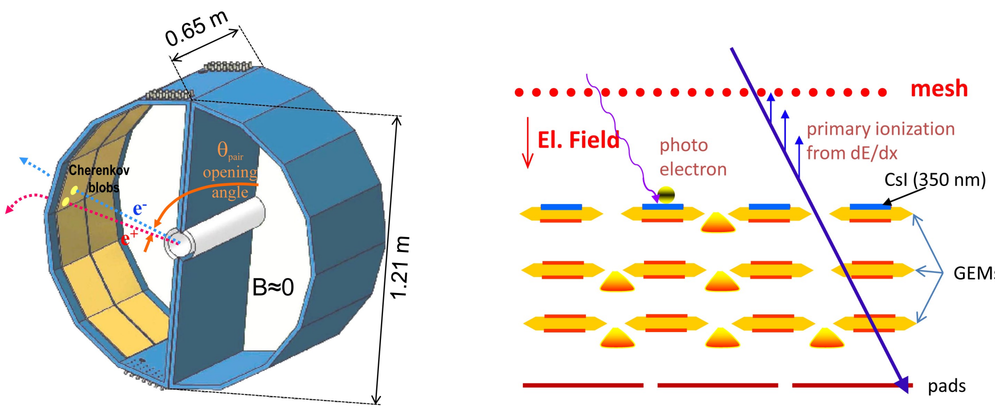

Figure 2: Left: HBD vessel with GEM modules. Right: the triple GEM stack with CsI photocathode on top of the first GEM and hexagonal pad readout in the bottom. The reverse field is created between the mesh and the top GEM to repel the ionization charge.

[1] N_0=370 $[ph/eVcm]\int_{E_{min}}^{E_{max}} QE(E)dE$, where QE(E) is the quantum efficiency and the integral runs over the sensitive bandwidth of the detector.

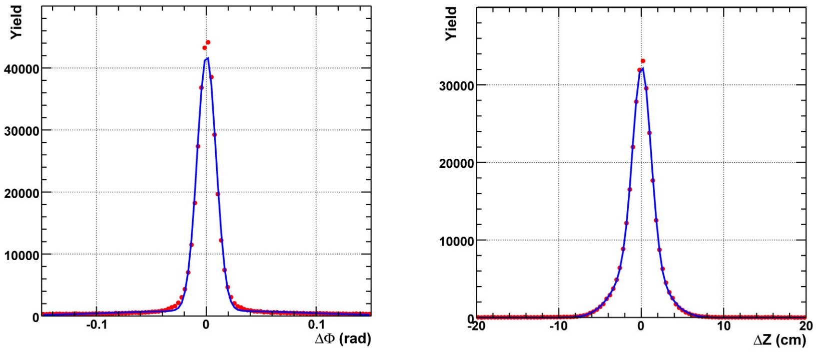

Figure 3: Matching of the single electron hits in the HBD to the central arms track projections in Φ (left) and Z (right). Data from 2009 Run.

The readout pad plane consists of hexagonal pads with an area of 6.2 cm^2, slightly smaller than the blob size which has a maximum area of 10 cm^2, therefore the probability of a single-pad hit by an electron is very small. On the other hand, if some of the hadrons traversing the HBD produce a small signal it will be predominantly localized in a single pad. This provides an additional handle in the hadron rejection of the HBD.

The detector is made of two symmetric arms, each of them covering 135° in azimuthal angle ϕ and ±45 units in pseudorapidity η. The whole detector contains 20 triple GEM modules. The radiation length of the HBD is ∼2.3%, where 0.74% comes from the vessel, 0.4% from the CF_4 gas and ∼1% are from the backplane and the electronics.

2.2. *Performance*

After extensive R&D [4, 5], the HBD was successfully installed in the PHENIX detector. It was operated in the measurements of e^+e^- pairs in p+p collisions at $\sqrt{s}$=200 GeV (2009 Run) and in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, 62 GeV and 39 GeV (2010 Run).

The HBD matching resolution is defined as the difference of the PHENIX central arm track projection point at the HBD surface and the position of the closest HBD cluster. Figure 3 shows the matching resolutions for single electrons. In the Φ direction the matching resolution is σ_Φ = 8 mrad (0.5 cm) and this is the intrinsic detector resolution, as the central arm tracks have a greater precision and hence a negligible influence on the resolution. In the Z-direction the measured resolution σ_Z = 1.05 cm results from the convolution of the intrinsic HBD resolution and the resolution of the vertex (σ_{vert} ∼1 cm).

The good hadron rejection is demonstrated in Figure 4 showing that hadrons leave significantly smaller signal in the HBD than electrons when the detector is operated in the reverse bias mode.

To evaluate the separation of single and double electron hits we selected a sample of fully reconstructed π^0 Dalitz pairs (m<150 MeV/c^2) in the central arms. If the two central arm tracks are matched to two separate clusters in the HBD we consider them single hits. On the other hand if both tracks are matched to the same HBD cluster we consider

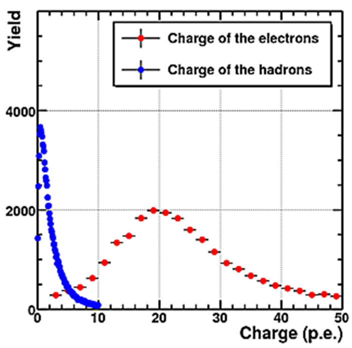

Figure 4: The signal produced by hadrons compared to single electron signal.

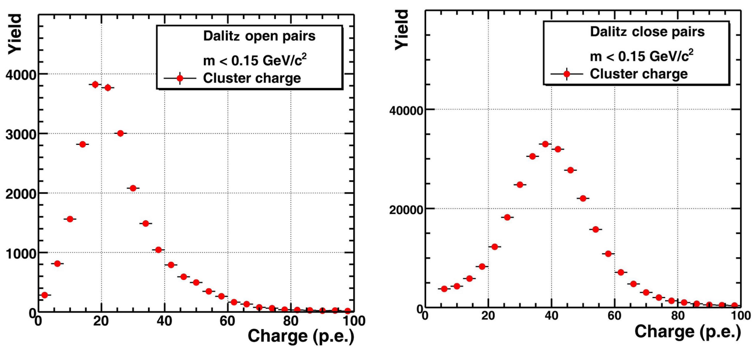

Figure 5: The signal measured by the HBD for single electrons (left) and double-electron hits (right). The data is from Run-9 p+p at $\sqrt{s}$=200 GeV.

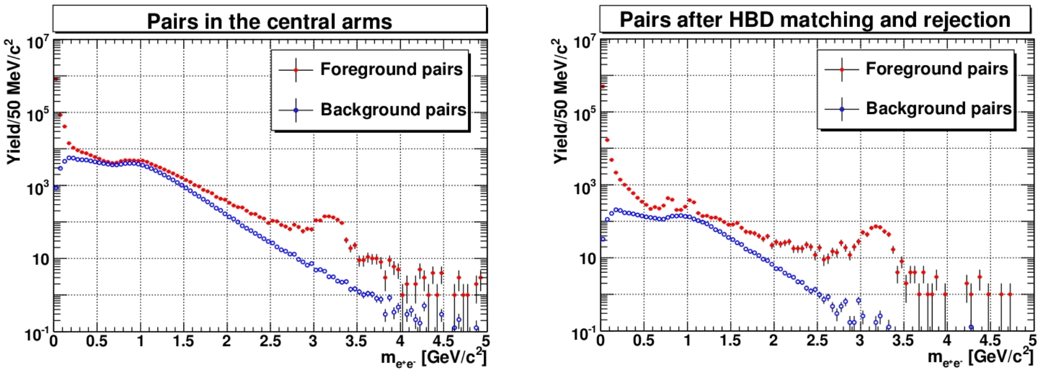

Figure 6: Left: dielectron mass spectrum derived using central arms. Right: mass spectrum using central arm tracks matched to the HBD + HBD rejection of double electron hits. The data is from Run-9 p+p at $\sqrt{s}$=200 GeV.

it a double hit. The signals in the HBD for the two cases are shown in Figure 5. The signal of single electron hits peaks at ~20 photo-electrons, while the signal of double hits peaks at ~40 photo-electrons. The high photo-electron yield, 20 per primary electron, corresponds to an excellent figure of merit N_0=330 cm^{-1} and ensures a good single/double separation and a high single electron detection efficiency. Preliminary results show an efficiency of 90.6±9.9%.

3. Status of the Dielectron Analysis

The benefit of using the HBD in the dielectron analysis is demonstrated with the p+p data from Run-9 at $\sqrt{s}$=200 GeV. The mass spectra in Figure 6 (left) are derived using PHENIX central arm detectors only. The foreground contains all e^+e^- pairs (the signal and the background), while the background spectrum represent the combinatorial background obtained by the mixed-event technique, hence the net signal corresponds to the difference of the former and the latter. The right panel in the same figure shows spectra derived using central arm tracks matched to the HBD and rejecting double amplitude hits. After applying HBD matching and rejection ω and ϕ-meson peaks become noticeable and the reduction of the background is significant. At the same time the signal in J/Ψ-region is largely preserved which demonstrates the high electron detection efficiency of the HBD.

The number of particles traversing the HBD in Au+Au collisions is much larger than in p+p collisions. These particles produce scintillation in the CF_4 resulting in a high detector occupancy. However, the scintillation photons are uniformly distributed over the photocathode, so the average signal can be subtracted on an event-by-event basis. This reduces detector occupancy in the most central Au+Au collisions from almost 100% to ~30%. The efficiency of this procedure was estimated using embedding of simulated electron tracks to the HBD data. The results show the efficiency stays ~90% in peripheral Au+Au collisions and it is slightly reduced to ~80% in the most central collisions.

4. Conclusion and Outlook

The Hadron Blind Detector was developed, installed and successfully operated in the PHENIX during RHIC Runs in 2009 (p+p) and 2010 (Au+Au). The p+p data demonstrate good position resolution, excellent electron detection efficiency, good hadron rejection and good separation of single and double electron hits. The scintillation background is successfully handled even in the most central Au+Au collisions. In the 2010 Run, PHENIX recorded 8.2 billion events at $\sqrt{s_{NN}}$=200 GeV and 700 million events at $\sqrt{s_{NN}}$=62 GeV. The analysis of these data sets is in progress.

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